A Methodology for Identifying Climatic Outliers in Living Collections

2026

A framework for arboreta and public gardens to identify species within their living collections that may be uniquely resilient to a changing climate.

Cover Image: *Quercus arizonica*, expected hardiness of USDA Zone 7 (International Dendrology Society, *Quercus arizonica - Trees and Shrubs Online*), under snowfall in December 2024 at The Morton Arboretum, a zone 5b/6a environment

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Overview

As climate change progresses, identifying climate outliers in a living collection can contribute to the resilience of the collection and provide unexpected opportunities for plant conservation and public education. The methodology, based on a process developed at The Morton Arboretum and outlined here, provides a framework for other institutions to find climate outliers that may be in their own collections to help guide climate adaptation and species selection planning efforts.

Background

From July through December 2024 The Morton Arboretum Collections and Horticulture department conducted a survey of the living collections to determine which plants were “climatic outliers,” plants with an expected USDA Hardiness Zone higher than The Morton Arboretum’s zones 5b and 6. The USDA Hardiness Zone map (Fig 1-2) shows the average annual temperature lows that can be used to determine where plant species are most likely to perform well based on cold tolerance. Our survey found 18 plant species with an expected hardiness of 7 and three plant species with an expected hardiness of 8 growing at The Morton Arboretum. These findings will inform our curation and plant collection practices moving forward.

Figure 1: USDA Plant Hardiness Zone Map zoomed into The Morton Arboretum showing a combination of zone 5b (expected annual low of -15 to -10°F) and zone 6 (expected annual low of -10 to -5°F) (United States Department of Agriculture). Until 2023, The Morton Arboretum was considered entirely within zone 5b (The National Gardening Association).

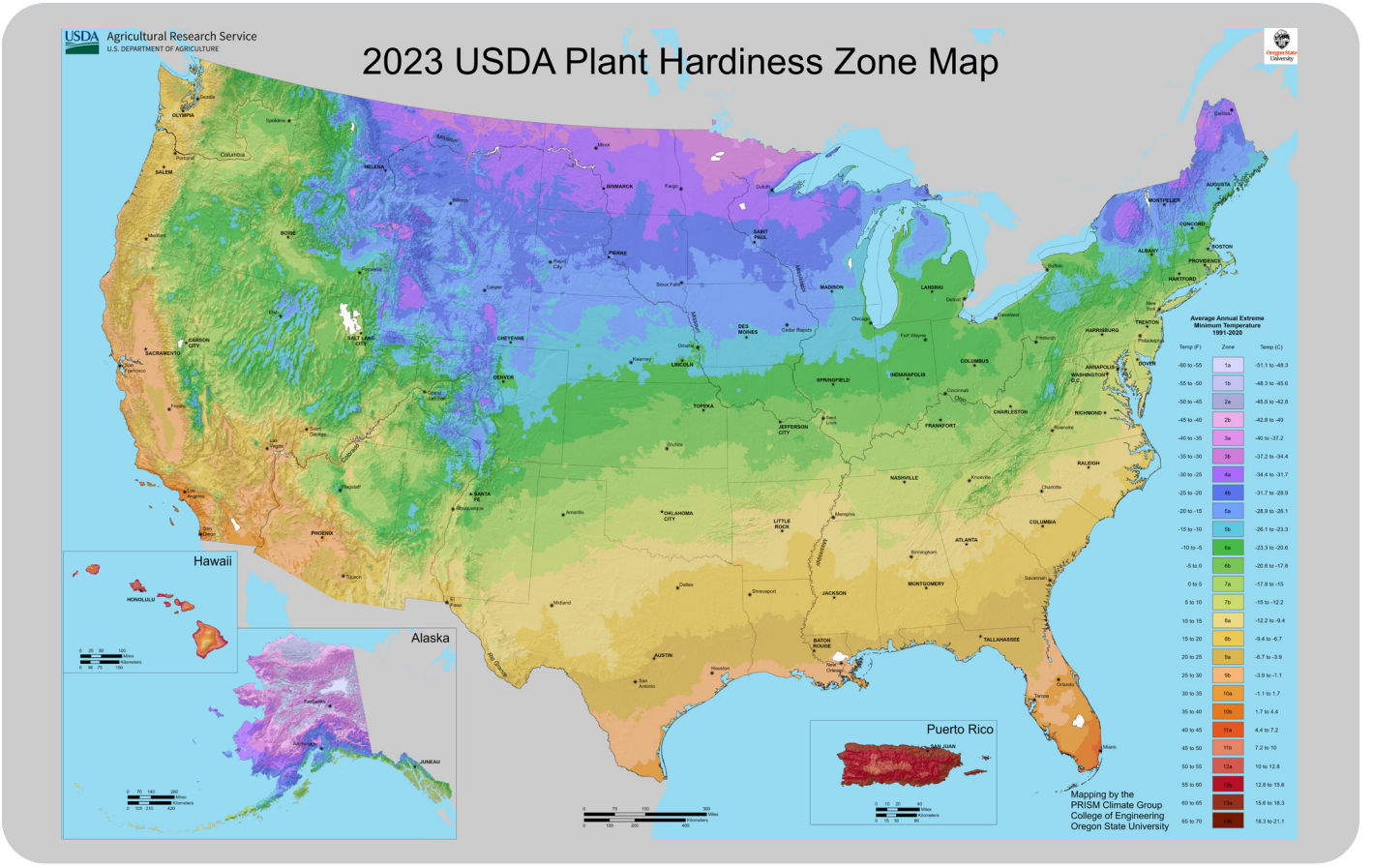

Figure 2: USDA Plant Hardiness Zone Map as of 2023 (United States Department of Agriculture).

1 Which plants are wild collected?

The first step of this process is to identify accessions of wild collected plants within a living collection. Cultivars and plants without a known wild provenance should be excluded since the goal is to find plants that have adapted to the climatic conditions of a particular site.

2 Where were these plants collected?

Determine a latitude and longitude for where each plant was collected, with precision that narrows the area down to an individual plant hardiness zone. Because it is only necessary to determine the climate zone where the plant was collected, precise coordinates are not needed. Locations like names of cities, towns, counties, parks, individual mountains, or lakes are ideal. Larger locations like states, countries, rivers, or sections of these areas (i.e. “southern Illinois”) should be refined further through additional information if possible. In addition to plant collection data from The Morton Arboretum living plant records database, herbarium (Fig 3-4), and archives (Fig 5-6) information from sources such as GBIF, USDA GRIN, and index semina (Fig 7) was used to generate a map of collection locations for The Morton Arboretum’s wild collected plants.

Figure 3: Herbarium specimen retrieved from GBIF showing collection location coordinates that matched the collection field number and collection date of a plant in The Morton Arboretum living collection that was missing coordinates in the plant records database (Global Biodiversity Information Facility, Occurrence 4064838396).

Figure 4: A plant in The Morton Arboretum living collection was described as being collected from Mayaku in China, a historical name no longer in use. This herbarium specimen of a different plant was also described as being collected in Mayaku and did have coordinates associated with it (Global Biodiversity Information Facility, Occurrence 730984475).

Figure 5: Several plants at The Morton Arboretum were recorded as being collected at Platt National Park, a former national park that is now known as Chickasaw National Recreation area (National Park Service).

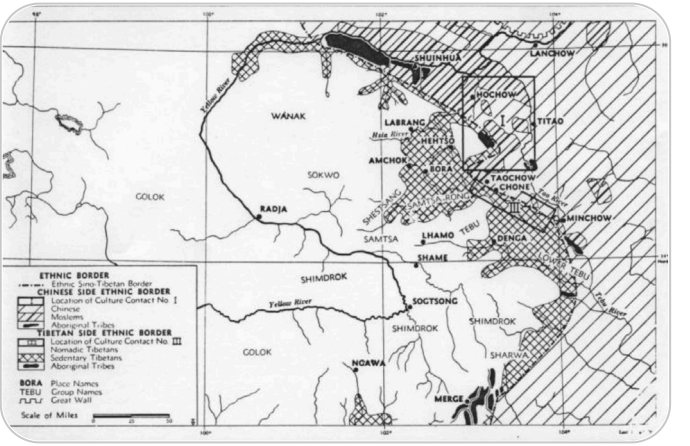

Figure 6: Historical map of Tibet that was used to determine the collection location of several plants whose collection notes referenced Titao, a name no longer in modern use (Ekvall, 1977).

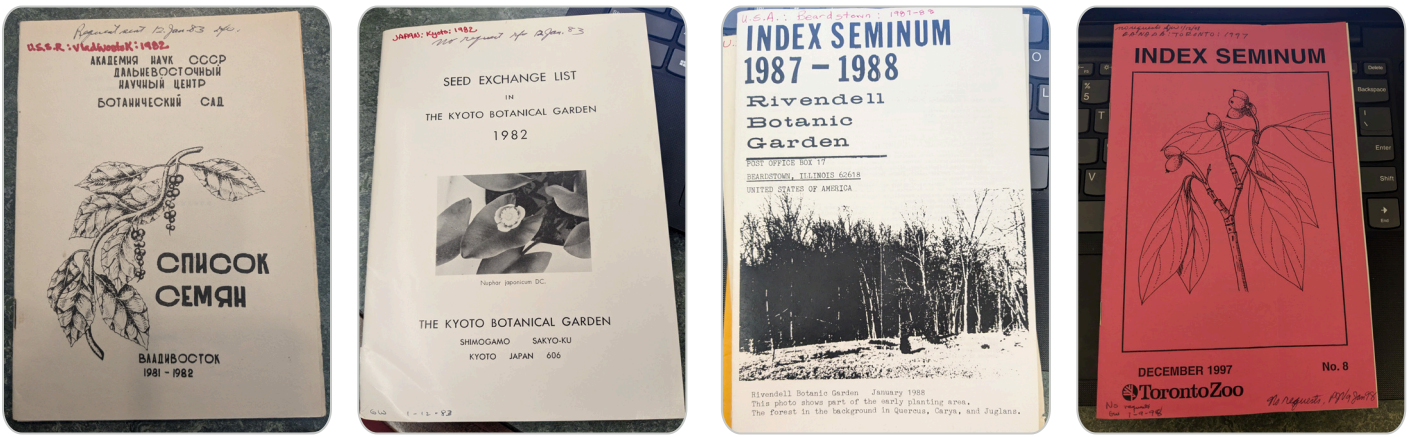

Figure 7: Examples of index semina from different public gardens that The Morton Arboretum has requested plants and seeds from over the years. These documents sometimes include location data not captured elsewhere.

For reproducibility and documentation, the OpenStreetMap API was used via the geopy Python library. This API takes a string (i.e. “Chicago, Illinois”) and returns a latitude and longitude. Both the search strings and coordinates for each plant were saved (Fig 8).

Figure 8: Google Map of the origins of wild-collected plants at The Morton Arboretum.

3 What is the climate like where these plants were collected (USA)?

For plants collected in the United States, find the USDA plant hardiness zone that corresponds to each collection location (Fig 9-10). A Python script which converts coordinates to plant hardiness zones using the geopy library was used for this step. This process can also be conducted manually without scripting by entering coordinates into the USDA plant hardiness zone search bar.

Figure 9: *Ulmus crassifolia*, expected hardiness of USDA Zone 7 (Dirr, 2009, p. 1177) at The Morton Arboretum.

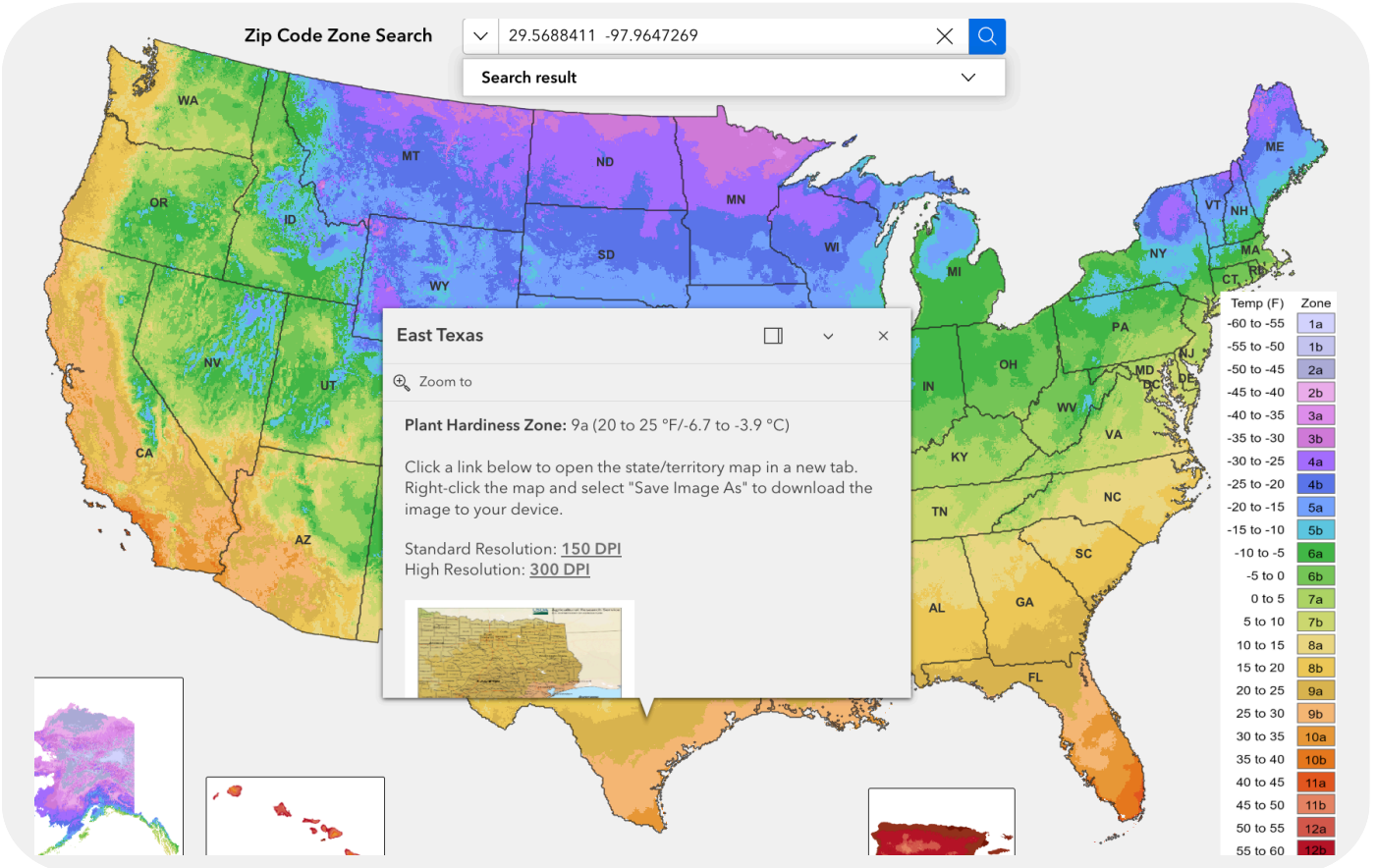

Figure 10: Coordinates of the collection site of the above *Ulmus crassifolia* entered into the USDA Plant Hardiness Zone map, showing that the location is in USDA Zone 9a (United States Department of Agriculture).

4 What is the climate like where these plants were collected (outside the USA)?

For plants collected outside of the United States, find the Köppen climate zone that corresponds to each collection location (Fig 11). The Köppen-Geiger classification system (Fig 12) divides the surface of the earth into 30 different climate types based on their average temperature and annual precipitation. A Python script which converts coordinates to Köppen zones through the kgcPy Python library was used to determine Köppen-Geiger zones for each location outside of the United States. This process can also be conducted manually by using the Köppen-Geiger map for Google Earth (Fig 13).

Figure 11: *Morus mongolica*, expected hardiness of USDA Zone 7 (International Dendrology Society, *Morus mongolica - Trees and Shrubs Online*) at The Morton Arboretum. This plant was collected outside of the United States, so the climate of its origin was determined using the Köppen-Geiger classification system rather than the USDA Plant Hardiness Zone map.

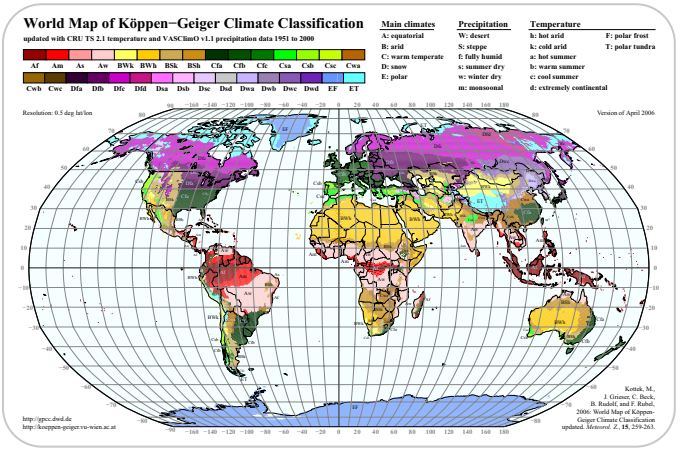

Figure 12: Köppen-Geiger map (Kottek et al, 2006)

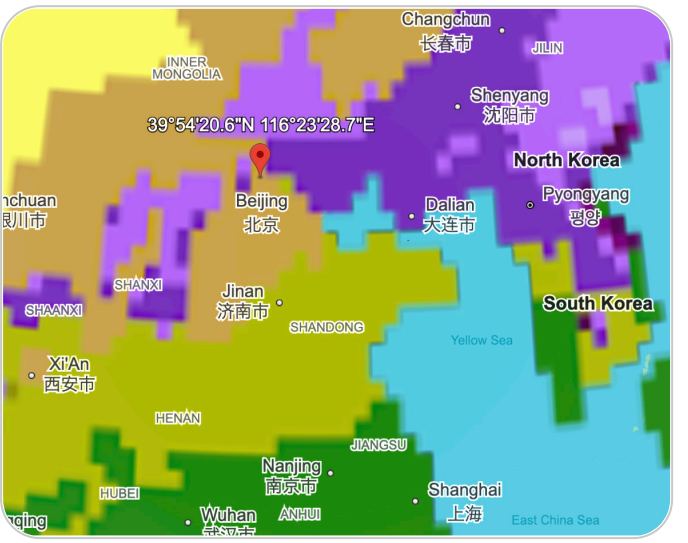

Figure 13: Coordinates of the collection site of the above *Morus mongolica* entered into Google Earth with the Köppen-Geiger map overlay showing that the collection site has a Köppen-Geiger climate classification of BsK.

5 Which of these plants are climate outliers?

To determine what constitutes an outlier plant, consider how the climate in your area will likely be changing. In the case of the Chicago region, the USDA hardiness zones of the region are expected to continue increasing, resulting in milder winters that more plant species can tolerate. In other regions, increased drought may be a more significant effect of climate change than increases in average temperature. Given The Morton Arboretum's current USDA hardiness zones of 5b and 6a, plants collected from areas with a USDA hardiness zone of 8a or higher were designated as climate outliers. Given The Morton Arboretum's Köppen climate zone of Dfa, plants from areas whose climate zone differed from each letter of this Köppen classification ("D," "f," and "a") were also designated as outliers. This meant plants collected from BWh, BWk, BSh, BSk, Csb, Csc, Cwb, Cwc, ET, and EF climate zones were designated as outliers (Fig 14). (There are currently no plants from the Af, Am, or Aw zones growing at The Morton Arboretum but these would have been marked as outliers if so).

6 What is the expected hardiness of these outliers?

A variety of sources can be used to determine this information. We primarily relied on the Manual of Woody Landscape Plants by Michael Dirr (2009 edition). For species not represented in this book, hardiness recommendations from Trees and Shrubs Online, extension publications, other public gardens, and nurseries were used.

7 What is the native range of these outliers?

A plant from a species which is known hardy in your region but originated in a region with a very different climate may have traits that provide resilience to climate change relative to the native gene pool in your area. Resources such as Plants of the World Online and the USDA Plants Database were used to find plant distribution maps.

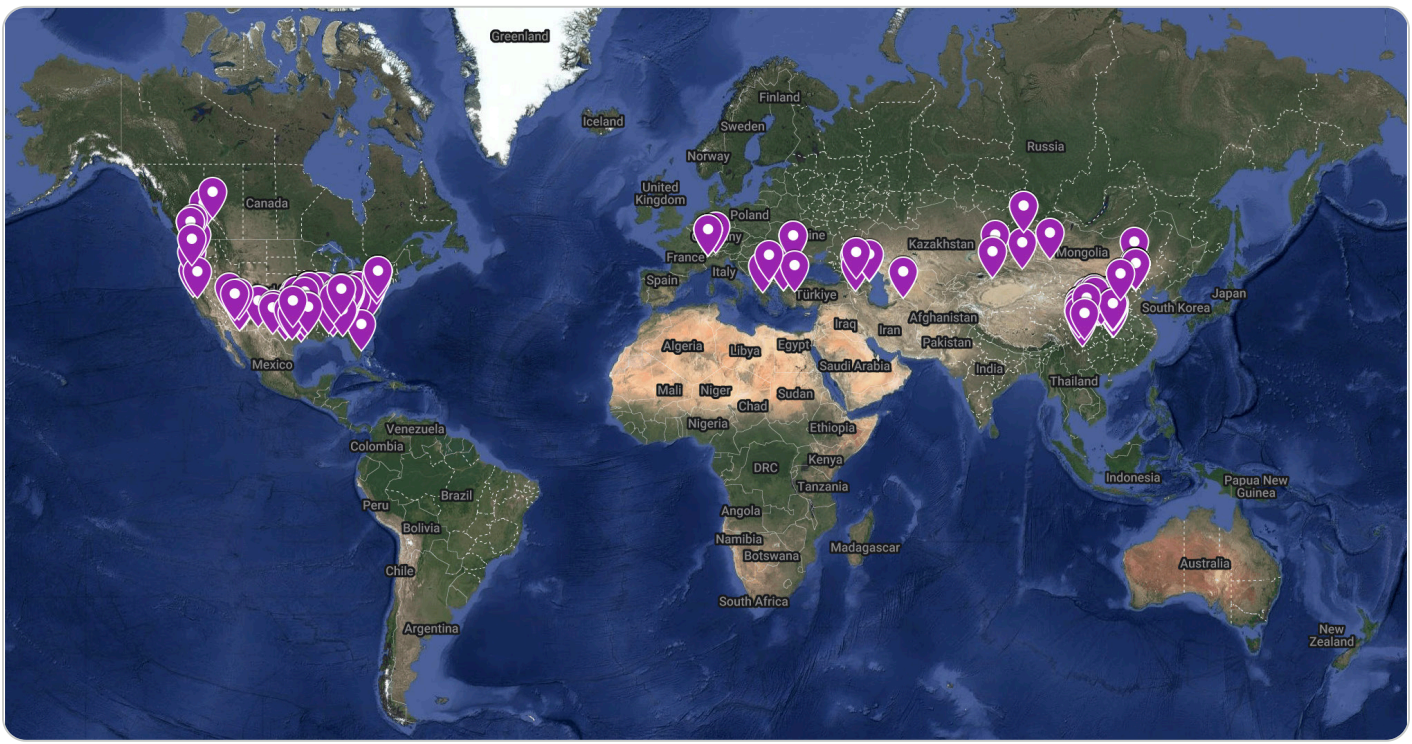

Figure 14: Google Map of the origins of wild-collected plants at The Morton Arboretum which came from outlier climates.

8 How have these species performed historically?

For each outlier species, The Morton Arboretum plant records database was queried for plants that are no longer living. The age of each plant and the reported cause of death was recorded. These ranged from plants that almost certainly died of cold stress to healthy plants that were removed for practical reasons.

9 How well are these plants doing in your collection?

Each of the climatic outlier plants was assessed using a 5 point scale developed by The Morton Arboretum Plant Records team (Fig 15-16). This scale is defined as:

1-healthy & thriving
2-slight problems; no setback
3-moderate problems; growth set back
4-significant problems, survival uncertain
5-poor condition, survival not likely

Figure 15: *Juglans major*, expected hardiness of USDA Zone 8 (International Dendrology Society, *Juglans major - Trees and Shrubs Online*) showing leader dieback (evidence of cold stress). The plant was given a health score of 3.

Figure 16: *Quercus boyntonii*, expected hardiness of USDA Zone 7 (Chicago Botanic Garden) showing no evidence of significant cold stress. The plant was given a health score of 1.

10 Which species are most promising?

Using the data from health assessments, hardiness expectations, and historical records, the outlier species were divided into the following groups:

a. Known cold-hardy species from an outlier climate (hardiness ≤ 6)
b. Species with hardiness ≥ 6, limited data so far (showing considerable cold stress)
c. Species with hardiness ≥ 6, limited data so far (no considerable cold stress symptoms)
d. Species with hardiness ≥ 6, sufficient data (showing considerable cold stress)
e. Species with hardiness ≥ 6, sufficient data (no considerable cold stress symptoms)

"Sufficient data" was defined as at least two living plants of that species planted before 2019. This year was selected because of a major weather event that occurred in 2019 in the Chicago area in which temperatures were below freezing from January 29 through February 1, with a low of -23°F (National Weather Service). This type of weather would be a typical annual extreme of a 4b hardiness zone, so plants that were able to withstand this event can reasonably be considered hardy in a zone 5b/6 environment.

"Considerable cold stress" was defined as at least 25% of the plants of the species were observed to have cold-related injuries that threaten the life of the plant, and/or at least 25% of recorded dead plants were documented as dying from cold-related injuries. While not from species that are unexpectedly hardy for the region, plants from category "a" are noteworthy in that these individual plants likely have adaptations to warmer climates not present in plants of the same species from cooler climates.

Category "e" indicates a species that is likely to perform well despite having a higher expected hardiness zone than the planting location.

Full results of The Morton Arboretum's climatic outliers identification process are shown in Table 1 and Figures 17-20.

SPECIES	COMMON NAME	HARDINESS	EARLIEST PLANTING	COLD STRESS
Acer oliverianum	Oliver's Maple	7	2021	yes
Alnus martima subsp. *oklahomensis*	Oklahoma Alder	7	2021	no
Cephalotaxus fortunei	Fortune's Plum-Yew	7	2021	yes
Holboellia fargesii	Farges Holboellia	7	2001	yes
Jasminum fruticans	European Jasmines	7	2017	yes
Morus mongolica	Mongolian Mulberry	7	1997	no
Platanus orientalis	Orientaal Plane Tree	7	2005	yes
Quercus arizonica	Arizona White Oak	7	2020	yes
Quercus boyntonii	Boynton's Sand Post Oak	7	2020	no
Quercus falcata	Southern Red Oak	7	2010	yes
Quercus laevis	Turkey Oak	7	2023	yes
Quercus mohriana	Mohr Oak	7	2020	no
Quercus sinuata var. *sinuata*	Durand's Oak	7	2020	yes
Quercus turbinella	Sonoran Scrub Oak	7	2022	yes
Schisandrea glabra	Bay Star Vine	7	1993	no
Silphium glutinosum	Stickey Rosinweed	7	2019	no
Ulmus crassifolia	Cedar Elm	7	1970's	no
Yucca cernua	Nodding Yucca	7	2020	no
Yucca pallida	Pale Yucca	7	2011	no
Acer cordatum	Purple-fruited Maple	8	2021	no
Carpinus pubescens var. *pubescens*	Yunghui Hornbeam	8	2021	no
Juglans major	Nogal	8	2022	yes

Table 1: Full list of climate outlier plant species identified at The Morton Arboretum as of fall 2024

Figure 17: *Acer cordatum*, expected hardiness of USDA Zone 8 (International Dendrology Society, *Acer cordatum - Trees and Shrubs Online*) at The Morton Arboretum. This plant was collected from Tupo, China, an area with a Köppen climate zone of Cwb.

Figure: 18 *Acer oliverianum*, expected hardiness of USDA Zone 7 (Dirr, 2009, p. 39) at The Morton Arboretum. This plant was also collected from Tupo.

Figure 19: *Carpinus pubescens* var. *pubescens*, expected hardiness of USDA Zone 8 (International Dendrology Society, *Carpinus pubescens - Trees and Shrubs Online*) at The Morton Arboretum. This plant was collected from Houhe Village, China, an area with a Köppen climate zone of Cwb.

Figure 20: *Alnus maritima* ssp. *Oklahomensis*, expected hardiness of USDA Zone 7 based on distribution (Flora of the Southeastern United States, *Alnus maritima ssp. oklahomensis*) at The Morton Arboretum. This plant was collected from Johnson County, Oklahoma, an area with a USDA Hardiness Zone of 8a.

Application

Using this methodology, public gardens and other institutions with plant collections can identify species already within their collection that may be particularly resilient to climate change. This can supplement ongoing research such as plant trials and breeding plants for heat and drought tolerance.

Climatic outliers also provide an opportunity to discuss climate change and plant adaptations for public education. In May of 2025, The Morton Arboretum featured some of the climatic outlier plants in the living collection in a series of tours (Fig 17).

Figure 21: Collections and Horticulture Fellow Terian Koscik discussing *Torreya taxifolia*, a plant endemic to the Florida panhandle, in a Trees of the Future Forest tour. Because this plant has an expected hardiness of 6 (Dirr, 2009, p. 1155), it would not have been considered hardy at The Morton Arboretum before 2023.

Acknowledgements

This project was funded in collaboration with the USDA Forest Service's National Urban and Community Forestry Challenge Cost Share grant and the Stanley Smith Horticultural Trust.

Glossary

Living collection: a group of organisms that are curated and documented within a particular area.

Wild collected plants: plants in a living collection which were collected from a natural habitat, either as mature plants or as seeds. These are distinct from plants whose origins are not known or were bred by humans.

Index semina: catalogs of seeds and plants that are exchanged between public gardens and other institutions (singular: index seminum). Today, these are generally published online, but were once primarily distributed as paper booklets. Because the institution describing a plant in an index seminum often collected the plant from the wild, collection location information is sometimes present.

Herbarium: a collection of dried, pressed plants, usually with information about when and where they were collected and by whom. Herbarium specimens are often collected at the same time as live plants or seeds and are given matching ID numbers, so living plants at a public garden and herbarium specimens can be matched.

Leader dieback: death of the primary stem of a plant.

References

1. **International Dendrology Society.** (n.d.). *Quercus arizonica - Trees and Shrubs Online*. https://www.treesandshrubsonline.org/articles/quercus/quercus-arizonica/
2. **United States Department of Agriculture.** (n.d.). *2023 USDA Plant Hardiness Zone Map*. https://planthardiness.ars.usda.gov/
3. **The National Gardening Association.** (n.d.). *The 2012 USDA Hardiness Zone Map*. https://garden.org/nga/zipzone/2012/
4. **Global Biodiversity Information Facility.** (n.d.). *Occurrence 4064838396*. https://www.gbif.org/occurrence/4064838396
5. **Global Biodiversity Information Facility.** (n.d.). *Occurrence 730984475*. https://www.gbif.org/occurrence/730984475
6. **National Park Service.** (2023, November 4). *Stories - Chickasaw National Recreation Area*. https://www.nps.gov/chic/learn/historyculture/stories.htm
7. **Ekvall, R.B.** (1977). Cultural Relations on the Kansu-Tibetan Border. *Economic Geography*, 16(3), 339. https://doi.org/10.2307/141503
8. **Dirr, M.A.** 2009. Manual of Woody Landscape Plants. Stipes Publishing L.L.C. Champaign, IL. (page 1177)
9. **Beck, H., Zimmermann, N., McVicar, T. et al**. Present and future Köppen-Geiger climate classification maps at 1-km resolution. Sci Data 5, 180214 (2018). https://www.nature.com/articles/sdata2018214
10. **Kottek, M., J. Grieser, C. Beck, B. Rudolf, and F. Rubel**, (2006). World Map of the Köppen-Geiger climate classification updated. *Meteorol.* Z., 15, 259-263. https://doi.org/10.1127/0941-2948/2006/0130
11. **International Dendrology Society.** (n.d.). *Morus mongolica - Trees and Shrubs Online*. https://www.treesandshrubsonline.org/articles/morus/morus-mongolica/
12. **International Dendrology Society.** (n.d.). *Juglans major - Trees and Shrubs Online*. https://www.treesandshrubsonline.org/articles/juglans/juglans-major/
13. **Chicago Botanic Garden.** (n.d.). *Quercus boyntonii*. https://www.chicagobotanic.org/plantcollections/plantfinder/quercus_boyntonii--boynton_sand_post_oak
14. **National Weather Service.** (n.d.). *Climate*. https://www.weather.gov/wrh/climate
15. **Dirr, M.A.** 2009. Manual of Woody Landscape Plants. Stipes Publishing L.L.C. Champaign, IL. (page 1155)
16. **International Dendrology Society.** (n.d.). *Acer cordatum - Trees and Shrubs Online*. https://www.treesandshrubsonline.org/articles/acer/acer-cordatum/
17. **Dirr, M.A.** 2009. Manual of Woody Landscape Plants. Stipes Publishing L.L.C. Champaign, IL. (page 39)
18. **International Dendrology Society.** (n.d.). *Carpinus pubescens - Trees and Shrubs Online*. https://www.treesandshrubsonline.org/articles/carpinus/carpinus-pubescens/
19. **Flora of the Southeastern United States.** (n.d.). *Alnus maritima ssp. oklahomensis (Oklahoma Alder)*. https://fsus.ncbg.unc.edu/main.php?pg=show-taxon-detail.php&taxonid=35041

Resources

1. **USDA Plant Hardiness Zone Map** (a map of the United States with zones designated by annual temperatures) https://planthardiness.ars.usda.gov/
2. **Köppen-Geiger classification system** https://koeppen-geiger.vu-wien.ac.at/present.htm (a map of the world with zones designated by annual temperatures and precipitation)
3. **The Royal Horticultural Society Hardiness Rating System** (describes a hardiness classification system used in the UK that can be converted to USDA hardiness zones since both are based on annual temperature lows) https://www.rhs.org.uk/advice/rhs-hardiness-rating
4. **The Royal Horticultural Society plant finder** (provides expected hardiness and other information about plants that can be grown in the UK) https://www.rhs.org.uk/plants/
5. **Trees and Shrubs Online** by the International Dendrology Society (expected hardiness and other information about woody plants) https://www.treesandshrubsonline.org/
6. **Global Biodiversity Information Facility** (GBIF) (a database of biodiversity information, including coordinates from many plant collection expeditions)
7. **USDA-ARS Germplasm Resources Information Network** (GRIN) (information about USDA plant and animal collections, including collection location records of plants shared with public gardens and other institutions) https://www.ars-grin.gov/
8. **Open Street Map** (a free, open source map of the world with an API that can be used for scripting) https://www.openstreetmap.org/
9. **geopy** https://geopy.readthedocs.io/ (Python library for geolocation scripting)
10. **kgcpy** https://kgcpy.readthedocs.io/ (Python library for converting latitude and longitude to a Köppen-Geiger climatic zone)
11. **Manual of Woody Landscape Plants** (our main source for determining expected hardiness) https://stipes.com/catalog/horticulture/manual-woody-landscape-plants-paperback/30
12. Tree species distribution range maps from **Little's "Atlas of United States trees"** series (distribution maps of plant species from North America) https://www.fs.usda.gov/database/feis/pdfs/Little/aa_SupportingFiles/LittleMaps.html
13. **Biota of North America Program (BONAP) North American Plant Atlas (NAPA)** (distribution maps of plant species from North America) https://bonap.net/Napa/Genus/Traditional/County
14. **Plants of the World Online** (extensive database of information about plants, including distribution maps and record of changes to taxonomic classification over time) https://powo.science.kew.org/
15. **National Oceanic and Atmospheric Administration** (data about historical weather events and weather trends over time in the United States) https://www.weather.gov/
16. **2023 USDA Plant Hardiness Zone GIS Datasets** (includes list of ZIP codes and their corresponding hardiness zone, useful for scripting) https://prism.oregonstate.edu/projects/plant_hardiness_zones.php
17. **Harvard University Herbaria & Libraries Index of Botanists** (includes plant collection location information through botanist journals and other records) https://kiki.huh.harvard.edu/databases/botanist_index.html
18. **Library of Congress database of maps** (can be used to determine coordinates of locations with historical names no longer in use) https://www.loc.gov/maps/
19. **New York Botanical Garden Herbarium** (database of herbarium records that can include plant collection information) https://sweetgum.nybg.org/science/
20. **Arnold Arboretum Archives** (research, articles, and other information which can be used to determine plant collection locations) https://arboretum.harvard.edu/research/library/archive-collection/
21. American Museum of Natural History **Amphibians of the World** reference (some historical amphibian collections use similar location terminology as botanical collections) https://amphibiansoftheworld.amnh.org/
22. **Biodiversity Heritage Library** (database of biodiversity research) https://www.biodiversitylibrary.org/
23. **The Gymnosperm Database** (expected hardiness for some conifer species) https://www.conifers.org/
24. **Missouri Botanical Garden Plant Finder** (expected hardiness and other information about plants that can be grown in the St. Louis, Missouri region) https://www.missouribotanicalgarden.org/plantfinder/plantfindersearch.aspx
25. **Denver Botanical Gardens Gardens Navigator** (expected hardiness and other information about plants grown at the Denver Botanical Gardens) https://navigate.botanicgardens.org/ECM_Home.html
26. **The Dawes Arboretum Arboretum Explorer** (expected hardiness and other information about plants grown at The Dawes Arboretum) https://dawesarb.arboretumexplorer.org/
27. **Oregon State University Landscape Plants database** (expected hardiness and other information about plants that can be grown in Oregon) https://landscapeplants.oregonstate.edu/
28. **University of Minnesota Urban Forestry Outreach & Research Lab Woody Plants Catalog** (expected hardiness and other information about plants that can be grown in Minnesota) https://trees.umn.edu/woody-plants-catalog
29. **Boone County Arboretum plant information** (expected hardiness and other information about plants grown at the Boone County Arboretum) https://bcarboretum.org/plants
30. **Chicago Botanic Garden Plant Finder** (expected hardiness and other information about plants grown at Chicago Botanic Garden) https://www.chicagobotanic.org/plantcollections/plantfinder/
31. Arizona State University **Virtual Library of Phoenix Landscape Plants** (expected hardiness and other information about plants that can be grown in the Phoenix, Arizona region) https://www.asu.edu/lib/camartin/Martin%20landscape%20plant%20library.htm
32. **Ringve Botanical Garden Garden Explorer** (expected hardiness and other information about plants grown at Ringve Botanical Garden) https://ringve.gardenexplorer.org/
33. **North Carolina Extension Gardener Plant Toolbox** (expected hardiness and other information about plants that can be grown in North Carolina) https://plants.ces.ncsu.edu/find_a_plant/
34. **The Morton Arboretum BRAHMS Online Database** (a public, online version of The Morton Arboretum living collection database) https://bol.mortonarb.org/